Emerging Energy-Efficient Industrial Technologies

Updated profiles of sample emerging technologies

Interim Report to

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Background

U.S. industry consumes over one-third of the nation's energy to produce a quarter of the nation's GDP. Increasingly, industry is confronted with the challenge of moving toward a cleaner, more sustainable path of production and consumption, while increasing global competitiveness. Innovative technologies are emerging and essential for meeting these challenges. At some point, businesses including users and technology manufacturers are faced with various investment decisions in new capital stock. At this decision point, new and emerging technologies, sometimes underutilized if at all adopted, often compete for capital investment alongside more established or mature technologies. Understanding the dynamics of the decision-making process is important to perceive what drives technology change and the overall effect on industrial energy use. To combat the barriers, Lawrence Berkeley National Laboratory (LBNL) and American Council for an Energy-Efficient Economy (ACEEE) published a report on "Emerging Energy-Efficient Industrial Technologies" in 2000, which assessed a list of emerging energy-efficient industrial technologies that potentially can be adopted in the market. The assessments have been used in various degrees for:

- identifying R&D projects;
- identifying potential technologies for market transformation activities;
- providing common information on technologies to a broad audience of policy-makers; and
- offering new insights into technology development and energy efficiency potentials.

The goal of the assessments is to collect information on a broad array of potentially significant emerging energy-efficient industrial technologies and carefully characterize sub-group key emerging technologies. The technologies are characterized with respect to energy efficiency, economics, and environmental performance. The results demonstrate that the United States is not running out of technologies to improve energy efficiency and economic and environmental performance, and will not run out in the future. It is shown that many of the technologies have important non-energy benefits, ranging from reduced environmental impact to improved productivity and worker safety, and reduced capital costs.

Many years have passed since the last publication; therefore, it is important to perform similar assessment based upon new information so that the profiles of selected emerging technologies are updated. The outcomes from updated profiles will provide and in some cases confirm the characterization of technology potential specifically to the technology and industries. With the support of California Energy Commission, LBNL is teaming up with ACEEE to develop new assessments using similar methodology described in the following. In addition, it is our intent to develop at least eight new technology profiles that address California industries and applications. The outcomes can serve as a guide or reference for future technology demonstration, market penetration, and policy making in promoting emerging or under-utilized technologies that are important to California industries.

The collective assessments began with the initial identification of approximately 300 emerging energy-efficient industrial technologies through a review of the literature, international R&D programs, databases, communications with stakeholders, and studies. The review was not limited to only California or U.S. experiences, but rather aimed to produce an inventory of international technology developments. In general, the preliminary screening process to select the technologies that had: (1) high potential energy savings; (2) lower comparative first costs relative to existing technologies; and (3) other significant benefits. While some technologies scored high on all of these characteristics, most had a mixed score.

Based on the literature reviews, the application of initial screening criteria, and feedback from stakeholders, the project goal is to identify and update profiles for 30 technologies with continued collaboration ACEEE. Each of the selected technologies has been assessed with respect to energy efficiency characteristics, likely energy savings, economics, and environmental performance, as well as what's needed to further the development or implementation of the technology. The technology characterization includes a one to two-page description along with a summary of the results for the technology. Eventually the information will be organized in an interactive database to be available on the website. At this stage of the project, we are including the profile updates in this report (in PDF format).

In the meanwhile, we will develop profiles for at least eight emerging technologies that are applicable to California industries. Overall, the technologies ranged from highly specific ones that can be applied in a single industry to more broadly crosscutting ones that can be used in many industrial sectors.

Updates and addition of emerging technology profiles

1. Refrigeration/Cooling (Food and Beverages)

Refrigeration in the food and beverage-processing sector uses significant energy and is mainly used for freezing, cooling, and storage of meat, fruit, vegetables, beverages, as well as for frozen products (e.g. ice cream, juice). Refrigeration in industry is most commonly done by compressive cooling, sometimes by absorption cooling (Mottal 1995), and possibly by solar thermal cooling. According to DOE EIA's MECS 2002, total annual energy input to Food and Beverage industries (NAICS 311 and 312) was 1793 Trillion Btu. Among this, 70 Trillion Btu was used for processing cooling or refrigeration. Electricity use for refrigeration in the food and beverages industry is mainly used by compressors.

Many options exist to improve the performance of industrial refrigeration systems. System optimization and control strategies combined show a large potential for energy efficiency improvement of up to 30 percent (Brownell 1998). Opportunities include system design, component design (e.g. adjustable speed drives), as well as improved operation and maintenance practices.

In the profile updates, we will focus on new system designs that include the use of adsorption heat pumps, gas engine driven adsorption cooling, new working fluids (e.g. ammonia, CO2), and in particular address alternative approaches (e.g. thermal storage, solar thermal cooling, etc.).

Due to the wide variety, we focus on selected technology developments in the areas of gas engines, thermal storage, new working fluids, and include in this new update solar thermal cooling, which shows great market potentials in improving energy efficiency and reducing GHG emissions.

In this working document on profile update, we will also include MagnaDrive, which is crosscutting and applicable to different industries.

Gas engines can be applied to drive the compressor instead of an electric motor. A gas engine is used as the direct drive, and the system can follow refrigeration loads by using variable engine speed. The waste heat of the engine can be used to preheat water or for space heating at the plant. GRI has developed a system, marketed by Thermopower Corporation, which has been tested in ice production, food processing, and chemical industries (GRI 1997). Other suppliers market similar products. NYSERDA supported an innovative demonstration at a dairy plant with a gas engine with an absorption chiller. Without the absorption sub-cooling, the project would have saved 52 percent on a primary energy basis. With the absorption cooling the project decreased primary energy use by 77 percent (CADDET 1996b). The gas engine compressor system (without absorption cooling) has capital costs twice as high as a chiller system, and a payback period of about 2 years. A similar system installed at Pittsburgh (PA) cooling warehouse had a payback period of 1.9 years (CADDET 2000b). The gas engine-absorption cooling system has substantially higher capital costs compared to an electric chiller system (almost a factor 3 higher), but the large energy savings and reduced peak energy use result in a payback period of 4 years. The use of a gas engine may result in higher onsite NO_x emissions, although offsetting high peaking power plant emissions. Hence, in non-attainment areas extra NO_x-reduction measures need to be installed.

Thermal storage is an “old” technology in the sense that it has been used for several centuries for seasonal cooling. Thermal storage has been re-discovered for applications in the food industry to shave peak loads by using off-peak power to generate ice, which is stored in a so-called ice pond and used for cooling. Several plants operate thermal storage systems in the U.S., combined with innovative cooling concepts, e.g. a fermentation plant in Rochester (NY), a cheese factory in Corfu (NY), a food services company in Clark County (NV) and a vegetable and food processing plant in Placentia (CA). Energy savings vary depending on the plant. The fermentation plant in Rochester (NY) reduced cooling energy needs by 80 percent compared to the existing mechanical chiller system. This system had a payback period of up to 4 years (CADDET 1993a). In other applications, the savings were not always fully documented or are much smaller. The load shift accounts for the productivity increase, as it allows the use of low-priced electricity at the off-peak hours. Given the current peaking power-supply problems in California, the Midwest and Texas, peak power is a highly valuable commodity, making this technology economically attractive. In the meanwhile, it should be noted that using thermal storage would often increase capital cost, and additional energy conversion and heat exchanges, making it less energy efficient despite the potential economic benefits from demand management or load shedding during peak hours.

Emerging refrigerants - Other major trends are a reduction of refrigerant charges and the development of *new working fluids*. Traditionally, the most common working fluids for compression heat pumps are ammonia and CFCs or HCFCs. R&D is directed toward alternative working fluids, especially for the CFCs and HCFCs due to the Montreal Protocol. These alternative working fluids can save energy. Savings of 2 to 20 percent have been reported (Trepp et al. 1992, Lorentzen 1993a, Lorentzen1993b). Recent developments include the use of natural refrigerants such as CO_2 (Stene 1999) or ammonia ((NH_3). CO_2 or NH_3 is suitable for cooling of storage facilities. In Japan, research has also looked at metal hydride systems for commercial cooling, as well as for small-scale systems. A first working prototype was demonstrated in 1995 at a very small scale (for a vending machine), and the technology has been demonstrated for a warehouse of 1100 ft^2 (100 m^2) at storage temperatures of 40^oF (-4^oC). The system can be designed in a wide variety of scales (10 – 10,000 kW), and reduces power use by approximately 20 percent compared to traditional CFC-containing systems (JNT 1996).

For the technology characterization, we will assume a potential for energy efficiency improvement of 20 percent on average, which can be achieved using different technologies, e.g. thermal storage, natural gas engine (not for non-attainment areas) and the use of new refrigerants in small-scale industrial applications. Higher energy savings are entirely possible in specific cases.

Given the incentives for reduction of peak power use and expected peaking-power shortages in important food producing regions, we assume that there is a substantial interest in implementing new refrigeration equipment in the food industry. Capital costs will depend heavily on the specific site and cooling conditions, as well as technology implemented. Hence, the costs and profitability of the investment will vary widely.

Most technologies, except for the use of selected new refrigerants, have been demonstrated commercially. Hence, dissemination of the results among other potential users is needed, as is demonstration of new concepts or innovative combinations of efficient cooling systems.

2. Emerging thermal cooling systems using renewable energy (new profile addition)

Solar thermal cooling technology is applicable for industrial process cooling (and heating) from renewable resource, i.e., solar energy. Applicable areas include a variety of food processing facilities, wineries, and grocery stores in which improved energy efficiency of yearlong industrial cooling or refrigeration is needed.

A typical solar thermal cooling system consists of solar heat collector, absorption chiller, hot-water storage tank, cooling tower, pumps, valves, and additional components. Different from a conventional chiller that uses grid-electricity to power the compressor in its refrigerating cycle to produce cooling, a solar thermal cooling system uses solar thermal collectors to produce heat that operates a conventional absorption or adsorption chiller that is thermally driven, and has no mechanically-moving components such as those seen in a traditional vapor compressor that demands high electric power. In addition, a compressor-based chiller typically uses HCFC or CFC refrigerant that is among the causes of depleted ozone and increases of green house gas (GHG) emissions, while absorption chillers typically use ammonia or a salt solution such as lithium bromide (LiBr) solution, which is non-toxic and environmentally friendly. The technology inherits benign energy and environmental impacts when applied in the industries.

The absorption chillers are essentially thermally driven that take advantage of solar heat collected to change the solution phases within its cycles, and only require a much-smaller amount of electricity to power liquid-circulation pumps. The water heated by solar collectors is used to initiate a thermal dynamic process involving low-pressure chambers that cools water to around 44 degrees Fahrenheit. The chilled water is then brought to a series of copper pipes that efficiently cool air blown through the pipes and into the space or process. Among a variety of promising solar thermal cooling technologies, LiBr-based chillers present a wide range of applicability and products in terms of their cooling capacity, safety, and services worldwide. Relatively speaking, a LiBr-based cooling system driven by solar thermal energy can provide a workable balance between its promising high-performance, simplicity, and reliability. The decreasing costs of solar panels and increasingly gained experience in their applications have made solar thermal cooling system more affordable and attractive that it was before. Solar thermal cooling technology (i.e., LiBr-based chiller driven by solar thermal heat) has been in fact beyond the “proof-of-concept” stage with a convincing proof of performance at a laboratory or a pilot scale. It has gained more market acceptance in Europe and Japan than in the US. Some recent studies were mainly focused on system design and improvement[1]. In fact, its commercial acceptance has been more benign and widely spread in Europe (e.g., 250+ installations) thanks to efforts within the European Union to combat global warming via

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[1] CEC Report 500-02-047F. Design and Optimization of Solar Absorption Chillers. MARCH 2002.

reducing greenhouse gas emissions. For example, a number of applications of absorption chillers of various cooling capacity have performed with reliability and safety in buildings or processing[2,3]. Unfortunately, its market acceptance and applications in California industrial sectors has been at most minimal due to a combination of barriers: technical and institutional. Successful demonstrations of applying such systems (e.g., medium-size systems – e.g., absorption chiller with 10-ton or more cooling capacity) in the US in pilot industrial plants (food or beverage) would be highly useful to diffuse the barriers due to lack of information and proof.

3. Emerging Technology – MagnaDrive variable speed drive (new profile addition)

Speed control via variable speed drive could reduce the power required by fans, pumps and blowers by up to 60%. However, all types of existing adjustable speed drives have penetrated only 9% of U.S. motor systems due to a variety of barriers.

An Emerging variable speed drive – MagnaDrive are becoming commercially available. It consists of two independent components without direct physical contact: 1) precision rotor assembly containing high-energy permanent magnets is mounted on the load shaft; and 2) conductor assembly with copper rings connected to the motor shaft. Relative movement between the magnets and copper rings produces a magnetic field that can transmit torque through the air gap between the two components. Varying the width of the gap changes the coupling force via magnetic induction, producing a controlled and continuously variable output speed. Good for pump, fan and blower applications, the MagnaDrive ASD is available in sizes ranging from 5 to 4,000 horsepower and speeds up to 3,600 RPM. The major advantages over common variable speed drives include:

- Lower maintenance and operating costs
- Minimized alignment problems and vibration that decrease bearing and seal life.
- Provision of speed control, increased reliability
- Lower footprint and harmonic distortion
- Motor systems can be resized for lower cost and operation that is more efficient.
- Allowing motor soft starts - operating at its optimum running torque and eliminating the need for a higher start-up torque that is required for conventional motors to meet its load.

The Northwest Energy Efficiency Alliance is working with the MagnaDrive Corporation to promote the company's patented coupling device in the region through market studies, technology validation tests and in-plant demonstrations. One case study shows that Ponderay Newsprint, Usk, Washington favored using an 18.5 size MagnaDrive Coupling (in lieu of VFD), which controlled the pumping process while eliminating the energy-consuming bypass valve. The coupling was connected to the pressure control loop. The pump's speed was controlled to maintain at 345 kPa (50 psi) pressure: Pump was at its maximum speed during the 12-minute de-inking cycle while the pump was slowed down

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[2] http://www.energysolutionscenter.org/resources/PDFs/GT_W03_Small_Absorption_Chillers.pdf
[3] http://www.solair-project.eu

during the 48-minute because flow demand was reduced. Energy demand for the 186-kW (250-horsepower) motor and pump drops to 65 kW from 173 kW – a savings of 108 kW (or saving 62% of the motor's energy use). Annual energy costs were reduced by approximately $18,800; in addition, it would potentially reduce demand charges in Ponderay Newsprint, Usk, Washington (NEEA).[4]

Another study in Daishowa America, Port Angele, WA, shows the application of MagnaDrive ASDs in its pulp and paper wastewater application. Regulating the speed of the pumps through MagnaDrive ASDs was significantly more energy efficient than controlling level through a bypass valve. The drives maintained the same 4800 GPM flow to the clarifier while reducing energy demand from 142 to 62 kW, a savings of 80 kW (or 56%). With continuous operation, this translated to a savings of over 700,000 kWh per year. In addition, the MagnaDrive ASDs eliminated damaging vibration and water hammer, resulting in equipment and maintenance cost savings of approximately $15,000 per year.[5]

In the Northwest, the fist cost of 15-year-lifetime MagnaDrive was estimated approximately $95/HP with assumed energy savings of a quarter resulting in annual savings of approximately 1200 kWh/HP. Conservatively, non-energy benefits is not included and annual O&M cost is minimal. It is estimated that market growth rate of the equipment is 25% for 2003 -2010.

Additional References

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[4] http://www.nwalliance.org/research/documents/MagnaDriveCS_Pnderay2.6.pdf
[5] http://www.nwalliance.org/research/documents/MagnaDrive_Daishowa_4.0.pdf